Reef Re-creation

Novel Restoration Strategies for the Osborne Tire Reef

By

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Abstract

In the early 1970s a failed effort at creating Osborne Reef, an artificial fishery, resulted in the release of two million tires into the Atlantic Ocean outside Fort Lauderdale, Florida, further endangering already threatened coral reef habitat. The tires blanket habitat areas and travel with ocean and storm currents, impacting delicate coral structures along the way. Efforts to remove the tires have proven inadequate at addressing this ecological threat. Through interviews and academic research we have studied the history and practice of artificial reef construction in general, and the Osborne Reef in particular. Proposed are a series of interventions created using parametric modelling techniques designed for three roles. First, they will neutralize the threat caused by the tires either by encapulating them under or accreting them along its structure. Second, they will mitigate tire-associated damage and loss and serving as a medium for coral and marine organism growth. Third, it will serve as a laboratory for novel marine ecological restoration techniques as a jointly managed public-private partnership.

Acknowledgements

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Statement of Purpose

This project proposes a novel landscape - scale strategy using emerging technologies to mitigate the deleterious ecological and environmental effects of the Osborne Reef, a failed artificial reef project implemented in the 1970's. While there exists a body of practices of reef construction, both recent breakthroughs in design technology and materials fabrication as well as the accelerating threat of coral habitat loss have driven the project authors to consider the efficacy of new systems of coral reef habitat creation. The proposal presented addresses both the specific considerations of the Osborne site while addressing some of the wider threats to coral reef systems worldwide, and in that vein can be considered as a test bed for a new typology of reef conservation strategy.

The Threat to Reefs

This project is proposed during a time of uncertainty for coral reefs ecosystems worldwide. Coral reefs, among the world's most biologically diverse and productive biomes, are threatened by a collection of issues at different scales (Pandolfi 2003). At the site scale coral reefs are acutely threatened by a collection of human activities. The mere presence of nearby tourist activity is a source of mechanical damage, while material exploitation of the reefs has degrading effects. This can take the form of fishing or pet trade collection, where dynamite is used to kill or stun wildlife, or the direct mining of reef limestone for a variety of uses (NOAA 2008).

Shore activities affect reefs on a wider landscape scale. Agricultural run-off from river systems into the ocean alters regional oceanic water chemistry to the extent that coral reefs cannot cope. Increased water turbidity from shoreline sediment causes wide-scale mechanical damage to reefs, as dissolved sediments scour the corals' delicate exterior living structure (NOAA 2008).

The effects of climate change remain the most systemic and serious threat to coral reefs worldwide. Climate change is affecting both the average temperature and chemical composition of the world's oceans (Shepard 2009). As increased atmospheric carbon is warming both the atmosphere and the oceans, increased uptake of atmospheric carbon into the ocean causes acidification. In either case, the corals that form the basis of reef ecosystems largely are adapted to the pre-climate change steady state conditions of the ocean and cannot cope with sudden changes.

Considering these multi-scalar challanges, this project looks to fix a novel problem at the site scale in a way that could develop into a way of restoring coral reef and marine habitats on a global scale, both in terms of technical innovation itself as well as the policy frameworks that would spur and sustain such innovation.

The Osborne Site

The Osborne site is situated in a complex of successive reef tracts off the coat of Ft. Lauderdale, Florida. It is comprised of three linear tracts of uplifted limestone coral reef that jut an average of 10 to 12 feet over the surrounding seabottom landscape, and run parallel to the Florida coast. The first reef tract is approximately 3,000 feet from shore at a depth of 15 to 20 feet. Severe beach erosion and shoreline development has denuded this reef tract of coral for some time (Foord 2014). The second reef tract is found 6,400 feet from shore at a depth of 40 feet, while the third reef tract is found 8,000 feet from shore at a depth of 50 feet. Both the second and third tracts contain coral habitat that is increasingly sparse as depth increases. Between the reef tracts are expanses of sandy bottom, a separate and complimentary habitat to the coral reefs. Seemingly lifeless at first glance, the sandy bottom hosts a variety of benthic lifeforms and supports stands of sea grass, another key near shore subhabitat. Rather than existing as separate biomes, the coral reef tracts, sea grass, and open sandy bottom function as an interdependent complex of habitats, with motile species utilizing the different habitat areas at specific times of day, year, or their own life cycles (Sheppard 2009).

The Osborne Reef was deployed in a 36-acre area of sandy bottom between the second and third reef tract, approximately 7,000 feet from the shoreline at a depth of 65 to 70 feet. At the time the artificial reef was conceived, the ecological value of sandy bottom habitat was not popularly recognized.

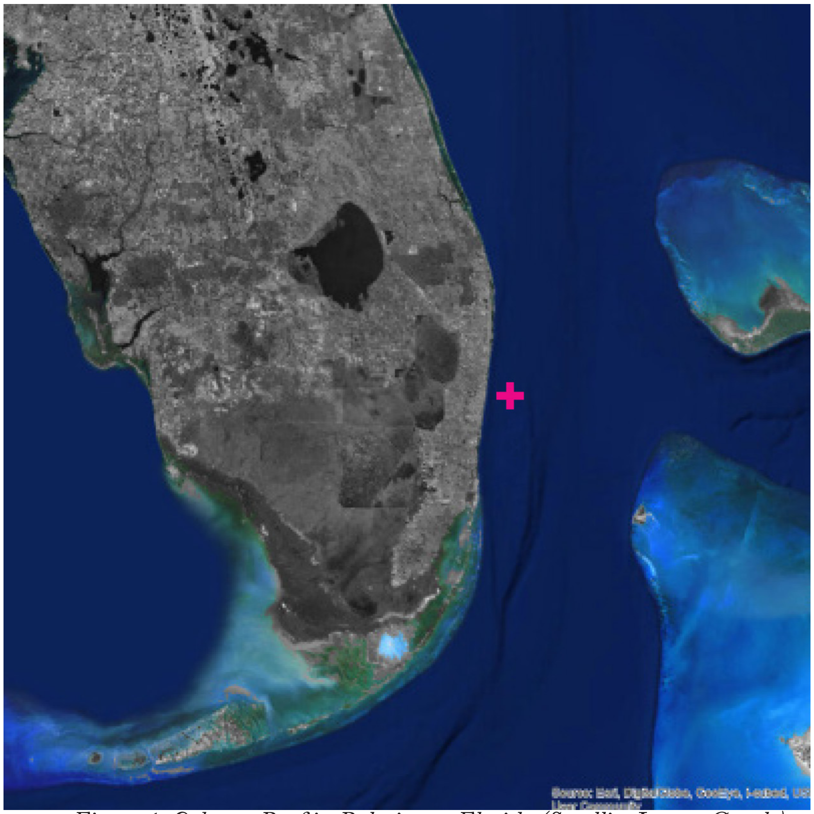


Figure 1. Osborne Reef in Relation to Florida (Satellite Image: Google).

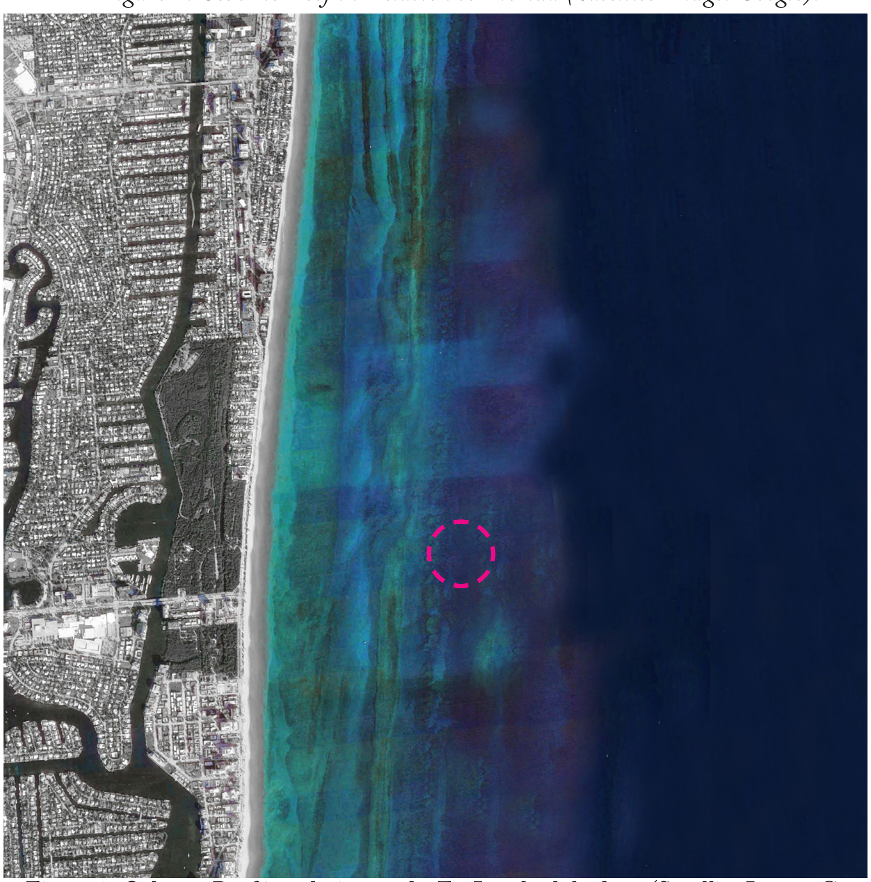
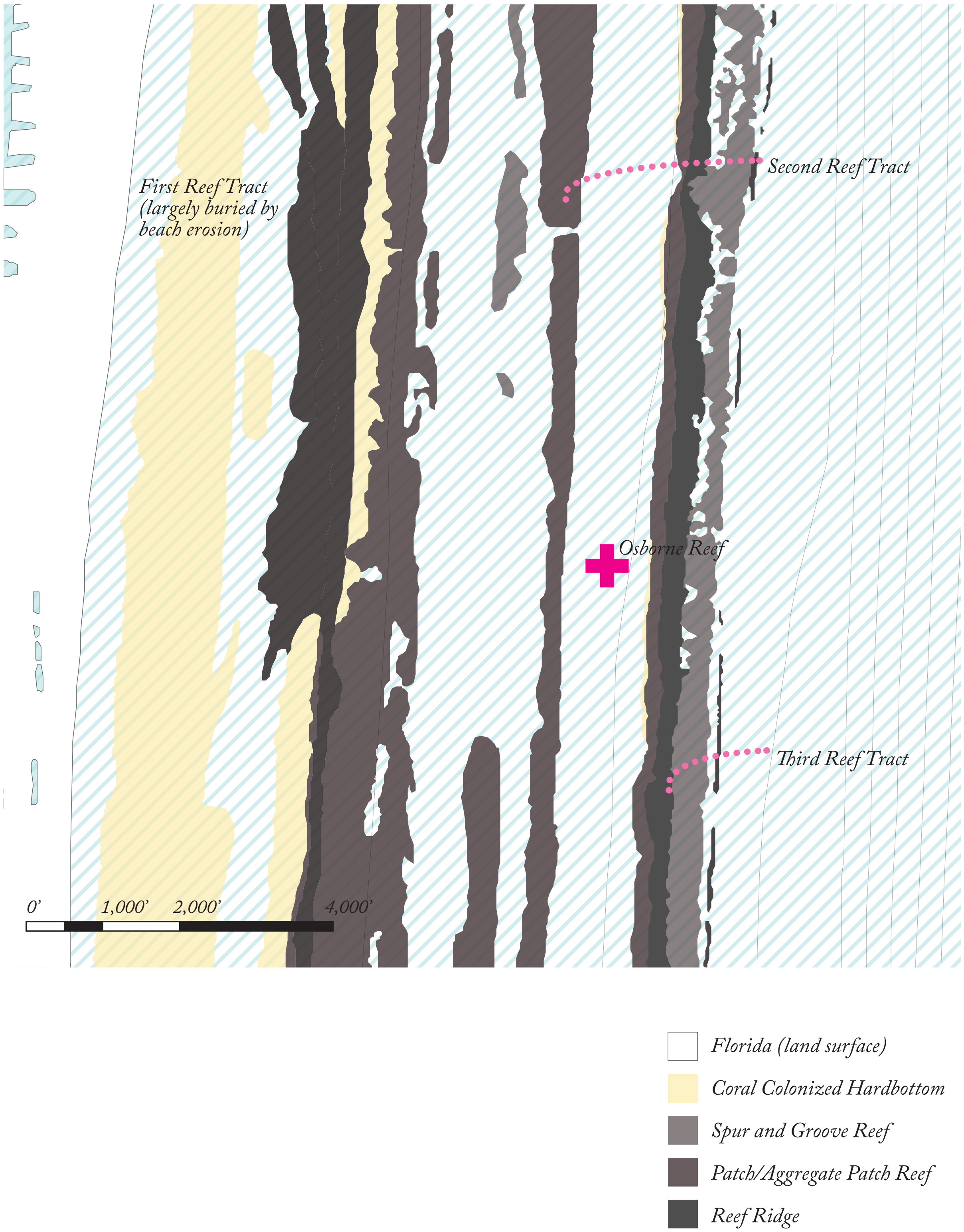


Figure 2. Osborne Reef in relation to the Ft. Lauderdale shore (Satellite Image: Google).

Figure 3. Osborne Reef in withing the surrounding reef tract complex.



The History of the Reef

The Osborne Reef was originally conceived by Broward Artificial Reef, Inc., a private LLC that approached the government of Broward County with a plan to proactively reform the county's tire disposal program (Project Baseline 2014). At this time tire recycling was not a widespread practice and was not considered a cost-effective option for the holders of the then-burgeoning stockpile of spent tires. BAR Inc. proposed that Broward County's junked tires be used to deploy an artificial reef concept developed by the Goodyear Tire Company's research and development labs in the early 1970's. Goodyear was aware how difficult their tire products were to dispose of and were motivated to find aftermarket uses for their waste stream. Goodyear's reef system that BAR Inc. proposed consisted of binding tires together into a series of horizontal columnar rows with steel clips and nylon straps. The columns of tires would then be released into the ocean where they would sink and theoretically settle on the seafloor (Candle 1982) . The forms would work as an attractant for sea life and over time, the surface of the tires be colonized by coral growth.

The reef project was seen as a win-win scenario. Over time, these tires would transform themselves from a spent product to ecologically valuable fishery; closing a waste stream while creating economic benefit. The plan was enthusiastically embraced by Broward County, who found partners in the US Army Corp of Engineers, who permitted the building of the reef, and the Goodyear Tire Company, who provided substantial material support. In 1972 the first portions of the reef were supplemented with a donation of one million used tires from Goodyear (Sherman 2006). The tires were loaded onto a fleet of barges and deposited into the ocean in a public ceremony officiated by Goodyear. The company celebrated the occasion by dropping a gold plated tire from thier iconic Blimp to christen the reef (Project Baseline 2014). The tires were added to an existing artificial reef composed of 50 concrete dolos (roughly jack-shaped structures). In subsequent years Broward County added to the reef through a collection program. Collection fees helped pay for a summer work program where collected tires were bound into columns prior to deployment. The County also permitted the dumping of individual tires into the reef site as a way of building up the reef site. Through these activities, the Osborne Reef gradually grew to include an estimated two million tires (Sherman 2006).

Over time the deleterious effects of the project began to become more apparent. Ultimately the location of the tires and their materiality prevented any significant coral formation (Morley 2008). The reef tracts that host coral generally rise 10 to 12 feet above the surface of

Figure 4. Deployment of the Osborne tires in 1972 (Photo: Morely 2008)

Figure 5. Present – day conditions in a densely packed portion of the reef (Photo: Project Baseline 2014).

the sandy bottom. This difference in height protects coral from the scouring effects of sand disturbed by ocean currents. Osborne Reef was situated squarely in the sandy bottom where sandy shore created a hostile environment for coral to form on (Sherman 2006). Adding to that, the loose binding of the nylon straps, lack of attachment to seafloor bedrock, and relatively buoyant qualities of tires led to them being continually jostled by the current. Corals require an immobile surface to successfully affix to. The motile tires proved categorically ineffective at attracting coral growth.

Ultimately, the nylon straps holding much of the artificial reef together proved ineffective and began to degrade. These tires, along with many of the tires individually released by boaters, were dispersed by prevailing northward ocean current, as well as less-frequent but more-powerful waves from seasonal tropical storms and hurricanes (Sherman 2006). These continual dispersals had several deleterious effects. As the tires dispersed and settled flatly across the seafloor they failed to provide the vertical structure necessary to attract fish. At a minimum, artificial reefs have been build to attract fish, and Osborne Reef was unable to meet this performance characteristic (Morley 2008). In areas where this blanket of tires is dense (anywhere of 1 to 6 "tires" deep) they act as a barrier to the sandy bottom, impacting the functionality of those habitats to some life forms. By far the most concerning quality of Osborne is the mobility of its tires. Freed from their restraints or indeed, never restrained in the first place, many of the tires have been widely distributed by ocean currents. These tires have gone on to become directly harmful to coral habitat the artificial reef was hoped to boost. Propelled by current, many of the tires travel freely until blocked by underwater landforms formed by the coral reef tracts. Blocked by the tracts, the tires batter their surfaces, destroying coral structures in the process through mechanical action. Approximately 350,000 tires are believed to have come to rest along the second reef tract alone (FDEP 2009). Once situated on the reef tract these tires prevent any coral regrowth through continuous jostling from ocean currents. Many other tires have travelled further afield, causing damage to coral habitat elsewhere and also creating a trash nuisance on the shore. Starting in the late 1970's tires washing ashore from Osborne Reef following storms has become routine, and tires associated with Osborne have been formed as far afield as North Carolina and Pensacola, on the opposite side of the Florida peninsula (Project Baseline 2014). In addition the tires dispersed onto nearby reef tracts and beyond, approximately 351,000 tires still remain within the original 36-acre dumping ground, and constitute a 'core infestation area' that all future tire dispersion events occur from. If the tires were to be considered a sort of invasive species, this would be the nest they are emerging from.

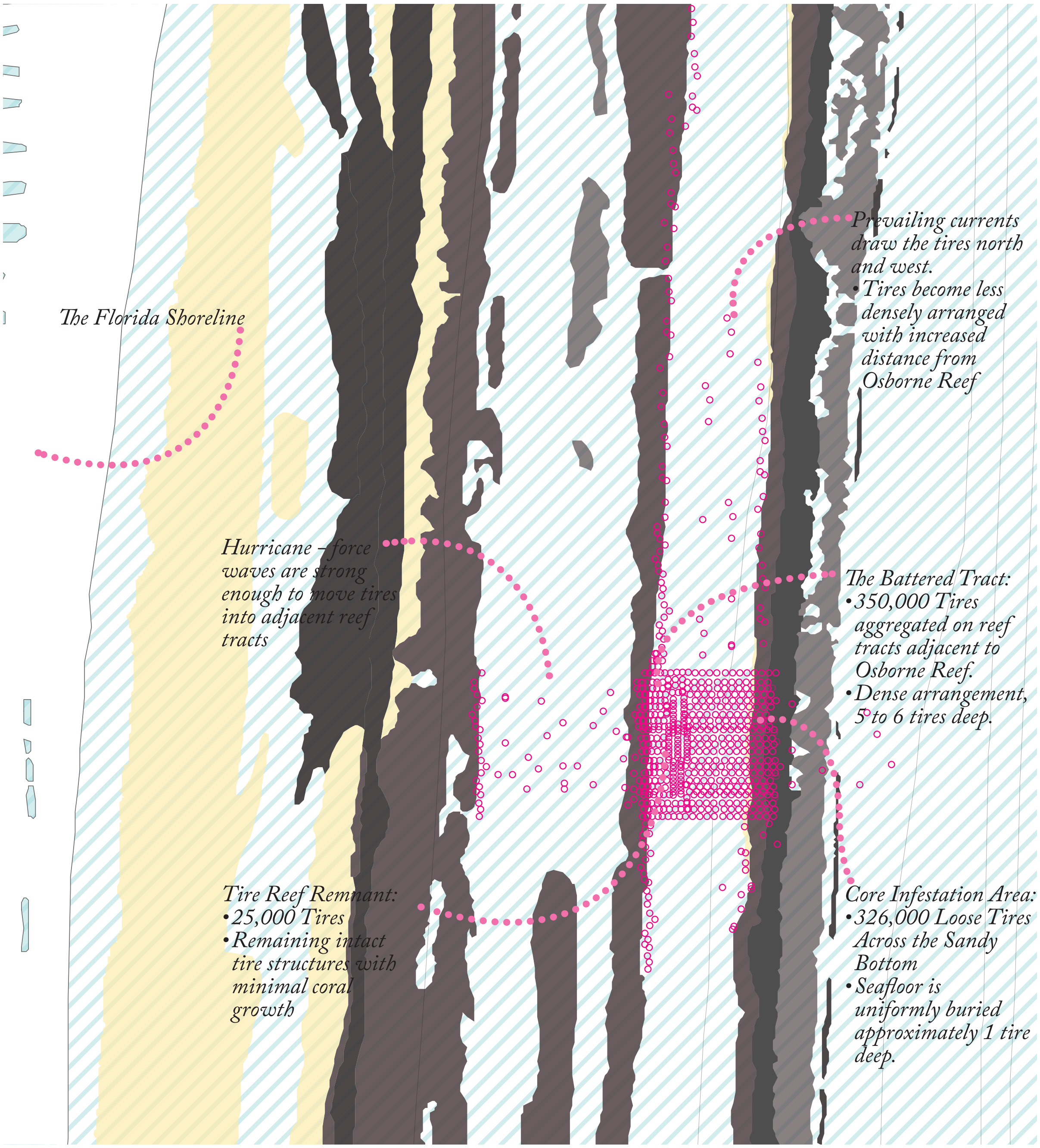


Figure 6. Distribution of Tire Contamination

As the scale of Osborne's failure began to reveal itself, a numerous initiatives have been implemented to deal with Osborne. Over time the reef has attracted a moderate and continual amount of attention from local, national, and international media sources, and numerous clean-up efforts have been attempted with various degrees of success. A tire removal pilot project initiated by Nova Southwestern University in 2001 collected 1,600 tires through the assistance of 86 divers over the course of 8 events. They were able to calculate a baseline cost of $17 per tire to manually remove the tires, for a total cost of $34 million dollars (Sherman 2006). Later estimates projected from a current removal program for total manual removal could cost anywhere between $40 to $100 million (Flescher 2015). By far the most successful removal activities have been undertaken by the military. From 2007 to 2009, regional divisions of the US Army, US Navy, and US Coast Guard paired their Florida-based rescue training exercises with tire removal activities, using the tires as a means to learning how to master manipulation of ungainly objects deep underwater. Military cleanup activities concentrated their removal on the core infestation area on the eastern side of the second reef and ultimately removed 73,000 tires before their program ended (Blue Water Intiative 2012, Project Baseline 2014). Currently, the only official program being conducted is a County-funded manual removal operation being conducted by a privately contracted dive team. Using a remaining $2 million in County grant funds allocated to Osborne cleanup, the dive team hopes to remove a minimum of 90,000 tires, at an estimated cost of $40 per tire (Flescher 2015) As of the time of publication, there are no further funded or otherwise systemic plans for removing or dealing with the tires.

One significant barrier to citizen-initiated cleanup are the unique regulatory challenges created by the Osborne tires. As stated, the tires are not optimum coral habitat, but are not necessarily coral-free. Under Federal law, any material with coral larger than 10 cm in diameter is designated as critical habitat (Quinn 2014) . Many of the tires meet this minimum criteria, regardless of those tire's very real ability to destroy other corals when moved by current. The law does not take that into consideration. This has the effect of relegating citizen-initiated tire collection to the category of guerilla action. Among the various unsanctioned collection events the most famous wa implemented by contemporary artist Hannes Bend, who in 2012, after collecting scores of tiers from the seafloor, recreated the Osborne reef in a Miami gallery space. The installation allowed the non-diving public to approach, view, and smell the tires that are otherwise unobservable directly to the majority of the public (Bend 2012).

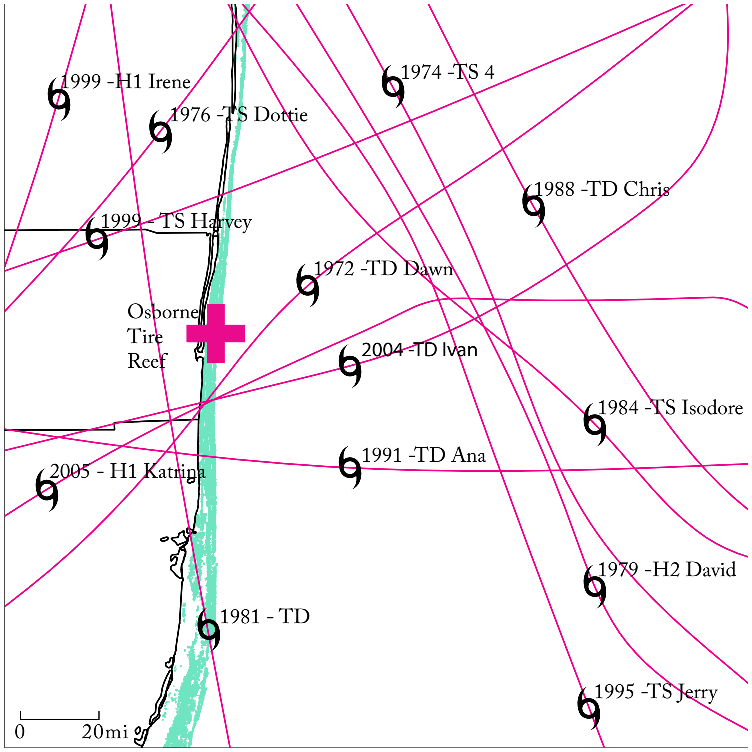


Figure 7. Hurricane Activity in the vicinity of Osborne Reef after deployment.

Figure 8. eclipse. Hannes Bend. 2012

Polemic

The construction of artificial reefs has long been a human activity, going back at least to the Classical period. The ancient Romans built reefs from stone rubble both to attract fish for food and commerce and to block enemy navies from approaching their cities (Stone 1985). The medieval Japanese created rubble reefs to encourage the growth of agricultural kelp (Mottet 1985). As time has progressed the practice of reef building has evolved both in its material consideration and complexity and in the more recent inclusion of ecological conservation as an explicit goal of reef building (Ladd 2012, Sheehy 1985).

Focusing on more recent examples, from the use of concrete jacks and to the sinking of subway cars and unused battleships, to experimental applications of mineral electrolysis and yes, tires, reef building in the 20th-21st century United States have been among the most diverse in form and function.

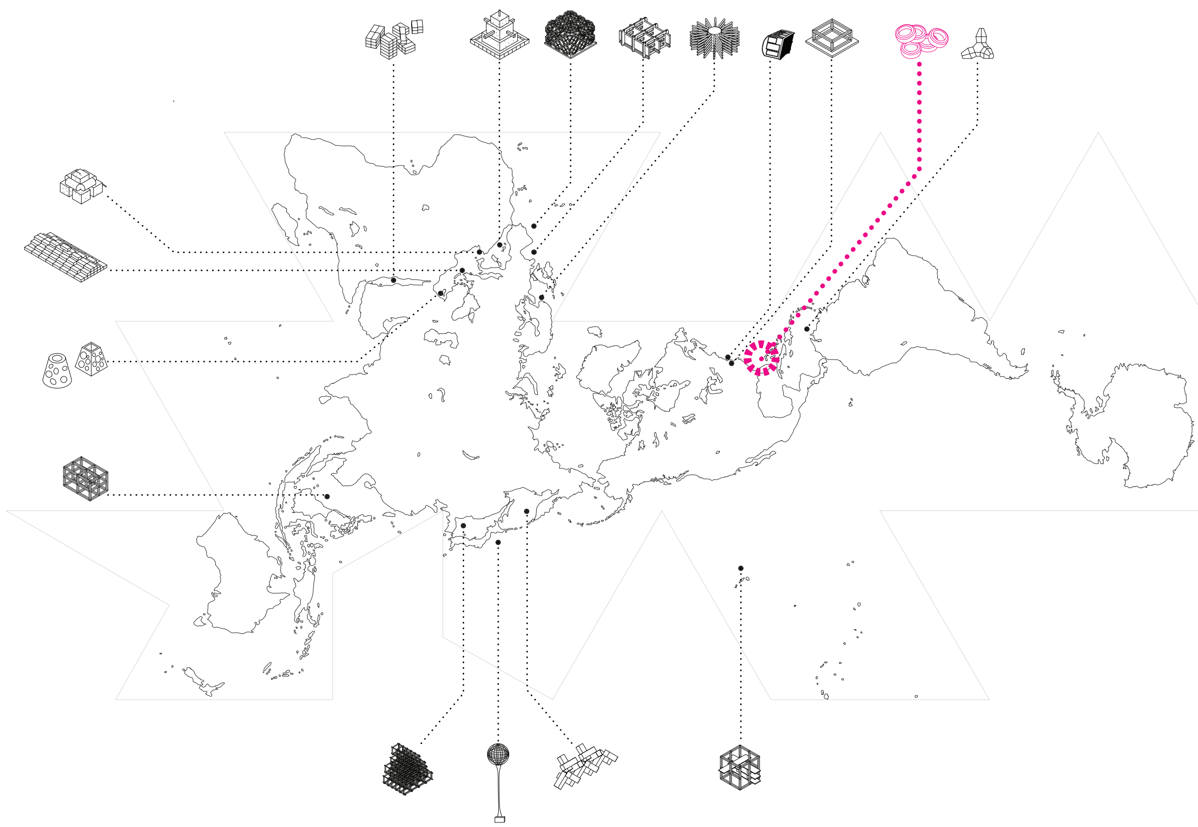


Figure 9. Worldwide distribution of assorted artificial reef typologies. Osborne Reef indicated in pink.

Arguably the most famous example of these artificial reef systems is the Redbird Reef, located off the coast of Delaware, comprising 619 outdated subway cars. Widely considered successful from an economic point of view, as it consistently attracts enough fish to maintain the area as a viable fishery (DNREC 2014). However, attracting fish is all this reef does, so it's success, like many artificial reefs, is one-dimensional in nature.

The Cancun Underwater Museum is a significant early reef that explicitly achieved multiple goals. This site successfully grows corals while providing explicit attractions for scuba divers, thus diverting them from more sensitive natural reef systems. This project marks an early transition towards multifunctionality. These early projects served as precursors to a new generation of ecologically driven projects derived from recent attention to threats such as rising sea levels, the degradation of oceanic ecological habitat, and the interconnectedness between the earth's environmental resources.

This new generation of projects also represents a more explicit connection between the fields of architecture and landscape architecture with aquatic, or coastal design, where architectural firms now directly engage in these projects and claim them as part of their disciplinary domain. One of the most significant projects was Kate Orff's Oystertecture. Part of MoMA's Rising Currents exhibition in 2010, this project envisioned artificially created oyster reefs off of New York City's coastline as a mechanism to clean harbor water, create jobs for those harvesting, producing, and using oysters, and also serving as a means for coastal storm surge attenuation (SCAPE 2010). Projects like this, while speculative in nature, have contributed a great deal to the discourse concerning future possibilities in the field of artificial reef creation, and will likely serve as a basis for future similar projects.

This project seeks to understand what is unique about this new generation of projects in a way that is relevant to the production of an artificial reef on the Osborne Reef site. Ultimately, two relevant defining characteristics inform our work: an acknowledgement of the technological and ecological complexity involved in the creation of these projects, and also a heightened focus on "systems thinking."

Technological advances have provided more powerful tools for designers to conceptualize, model, and construct solutions for degraded or damaged landscapes, as well as in the field of artificial reefs. Developments such as 3-D printing provide endless opportunities for the construction of artificial reefs. However, technological advances are not limited to the production of new material systems. Ultimately design challenges are becoming increasingly

Figure 10. Deployment of Redbird Reef (Photo: MD DNR Fisheries Service)

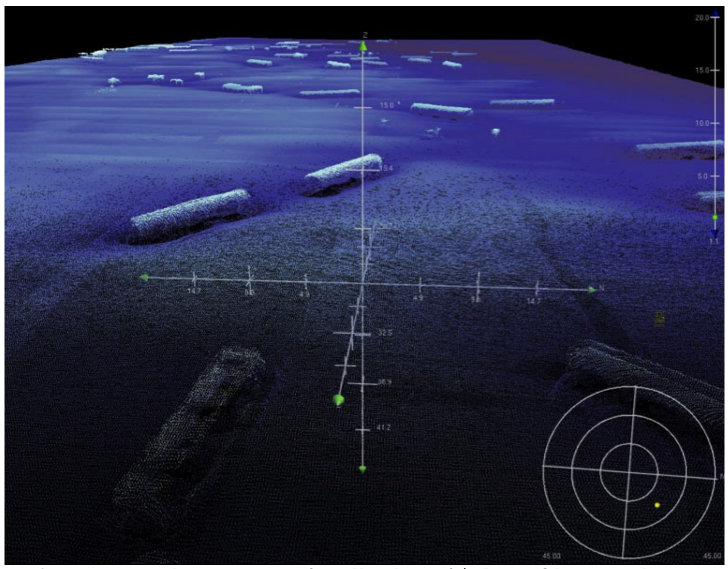


Figure 11. Lidar imagery of Redbird Reef (Photo: Chris Englert, UNH)

Figure 12. Present – day subway interior conditions at Redbird Reef (Photo: Landingarchitecture 2012)

complex, and new technologies provide further opportunities to develop solutions. That is to say this new generation can be equally marked by the complexity of the problems, as well as the sophistication of their solutions. (Moussavi 2003) Part of this complexity comes from designers' increased awareness of the connections between ecological systems.

This second trend is one of "systems thinking." Projects tend not to be conceived of as engineered systems, or artistic interventions. They are less often conceptualized as a bordered, defined site or object, with discrete performance criteria. Instead proposals emphasize connections, systems, relationships, and shared benefits. This conceptual shift has afforded new opportunities for ambitious designers to produce projects that are multifunctional when effective, and that introduce new ecologies and economic drivers when at their best. While many projects of this nature are rooted in an ecological or infrastructural need, the layering of recreational and economic systems justify the burdens these projects impose on the public. With proposals, such as HUD's Rebuild by Design competition (RBD 2014), the cultural climate for projects such as Reef Recreation is one where aspirational design ideas are not just encouraged, but necessary.

The disciplinary context for the Reef Recreation project is one that is rapidly advancing. Successful proposals combine increasingly complex and interrelated ecological, social, and economic factors. In turn, they generate a comprehensive program. Within this specific context, the Reef Recreation project seeks to use the environmental disaster of the Osborne Reef as a springboard to address the project's social, infrastructural, ecological, and economic demands.

All activites to date at Osborne have dealt only with removal of tires in an attempt to return the site to a pre-disturbance regime, though in the wider Florida conservation community a number of different restoration strategies are being approached. South of the site in the Florida Keys, historic restoration work conducted by Coral Restoration Foundation is being slowly and painstakingly performed on Staghorn Coral habitat (Coral Restoration Foundation 2015). Federal maritime protections for the area and the relative light disturbance of the area make this approach possible. Closer to our site, more radical restoration work is being conducted. Situated in Miami, the non-profit Coral Morphologic is conducting a breeding program to produce resilient hybrid coral strains that can withstand the now-harsh underwater conditions unsuitable to corals off the shores of Miami. Coral Morphologic makes no attempt to conserve the past for ecologica, economic, or aesthetic reasons. Nor are they setting out to necessarukty preserve a historic ecological function. Their mission is ecological in nature but embraces the reality that habitats are changing and being changed in unpredictable ways; their answer is to generate novel adaptation in the hope that such products will be productive in future ecologies (Foord 2014).

In contemporary ecology and wildlife management, historic restorations are only one strategy for creating sustainable and resilient wildlife habitat. In today's world, wildlife has to contend with adapting to rapid environmental changes brought about by rapid human development and climate change. In the face of such forces, historic restoration may not create habitat that is resilient in such new paradigms. Using the Osborne site as a test bed for new habitat remediation schemes gives restorationists the ability to try numerous schemes for success in the rapidly new world. Our project concerns establishing a framework that can accommodate the broad range of conservation approaches in order to find best practices in an uncertain future.

As a proactive alternative to mere tire removal and historic restoration, we propose an intervention that isolates the damaging effects of the tires at the site. Engaging the tires gives the intervention a reason to exist. Much like Coral Morphologic, the nature of the site disturbance is what gives an intervention a reason to exist in a wilderness area that would otherwise be left undisturbed. Removal alone will not allow an area to return to historic conditions if the world is changing around it. In essence, the tires give us the reason, the excuse to propose a radical restoration project that both neutralizes the tire threat while building the very reefs the original tire project failed at.

Performance Characteristics

Capture and Containment Ability

The single most damaging aspect to the tires is their mobility, then the first performance criteria to be considered is the intervention's ability to immobilize the tires in selected areas. The intervention will be designed to net the areas with the highest densities of tires per unit area, places where they are stacked over a tire deep for instance. This netting will contain large quantities of tires where they currently rest and prevent them from travelling elsewhere to cause further disturbance. Areas contained by the netting intervention will never be able to be restored, given the now-assured presence of the tires. Instead, it is the intervention itself that will mitigate the tire-initiated habitat degradation by generating new coral habitat itself. Over time, the intervention becomes less a structure purely for trapping the tires and more a novel coral habitat, though the latter outcome would strengthen the former. Taking advantage of corals' accretive properties, the subsequence growth of coral onto the structure would have the effect of "stitching together" the intervention more fully, effectively helping to entomb the tires buried beneath.

A Protective Barrier

Not all of Osborne's tires are densely arranged. As currents and wave action disperse the tires, they become more diffusely spread across the sandy bottom. While diffused, the tires continue to move until collecting against the reef tracts that block their motion; in effect the tracts begin to accreate tire buildup. In areas of low tire density it is not practical to trap tires with a net. It would be an enormous amount of effort for little containment payoff, and would also close off large portions of sandy bottom habitat unnecessarily. Instead, to address this iteration of the tire threat, a barrier intervention is proposed to protect the reef tracts in the path of diffuse tires. Such a barrier would be deployed adjacent to threatened portions of reef tract and act as a barrier to deflect impacts from incoming tires. Over time, tires would accrete on the barrier rather than the reef tract. Over time accreting tires could be removed manually or indeed, portions of the barrier could be converted into the netting structure described earlier.

Modular Components

Twin challenges to this proposal are both the difficulty of and cost associated with construction on the seafloor at the scale suggested by project prompt. Construction via modular components solves both problems. Rather than attempting a large scale construction project 70 feet underwater, the intervention, much like the tire reef proceeding it, could be constructed on land as a series of smaller components, to be fitted together on site incrementally. Discrete components could be more easily manipulated underwater, reducing the need for heavy equipment and additional cost. Modular construction also reduces the cost footprint over time. Production could be scaled up when funding is available and reduced when not. A modular approach does not take away from the functionality of the system. Instead, each component would have some containment and habitation creating capability of its own that would be enhanced as companion units are joined on the seafloor. With a modular approach life imitates art in sense, as much like the growth of coral structures, so would the growth of our reef intervention accrete over time.

Emulation of Reef Characteristics.

Height

Proper height is critical for our reef to successfully host coral. Florida's reef tracts jut 10 to 12 feet above the sandy bottom seafloor. In general, successful coral reefs need to be elevated a minimum of ten feet above the surrounding seafloor to avoid the abrasive effects of sand turbidity, otherwise known as sand scour. Any portion of the reef intervention intended to host coral growth would need to be at least 10 feet tall to present surfaces out of the sand scour zone for coral colonization. Placing potential habitat high above the seafloor also has the advantage of increasing its exposure to sunlight, which otherwise is gradually more obscured with increasing water depth. Access to sunlight is important for the many photosynthetic life forms that make up coral reef ecosystems, and increased sunlight will result in a more robust ecosystem developing.

Microhabitat

Microhabitat refers to localized subsets of the larger habitat, often with slightly or significantly different environmental conditions than the habitat surrounding it. Microhabitat is critical for ensuring room for the diverse niches that exist in coral reef ecosystems. Coral reefs are characterized by a high diversity of organisms, many in direct and fierce competition with one another, much more so than in many of Earth's other biomes. To allow for a high density of competition. Our intervention needs as much microhabitat as possible in the form of sheltered spaces. Such space allows for room for organisms to hide from predators, build nests, or affix themselves when entering a sessile life stage. The establishment of ample spatial microhabitat will be accomplished both through the design of the intervention, the choice of material used to build it, and it's method of manufacturing.

Composition and Material Precedents

The materials involved in constructing our reef intervention must themselves meet specific criteria in order to successfully serve the project. The intervention must be strong enough to constrain the tires and support coral growth, yet not so resistant to forces that it be carried away by hurricane waves! It must be heavy enough that when assembled it stays in place yet light enough that it can be assembled without heavy equipment.

This project is intended to be a test-bed for both established and developing best practices in reef construction. In keeping with this principle, the reef could be constructed with a variety of material types to test the advantages, strengths, and weaknesses of each. As breakthroughs in material science continue to progress, future portions of the intervention's gradual expansion could be constructed with selected new materials to test their efficacy for reef building. While material selection would be an ongoing process, our project has identified candidate materials to begin with, principally amended concrete with the potential for manufacturing via 3-D printing and electrolytic metal formwork.

Concrete is an excellent candidate for reef construction owing to it's physical and chemical malleability and availability as a 3-D printing feedstock. Coral reefs thrive on bedrock with specific chemical characteristics. Corals off the Florial coast thrive specifically on oolitic limestone: calcium carbonate rich sedimentary rock composed of ovoid granules that give a complex surface structure. Using chemical additives, concrete can be created that emulates the structural and chemical characteristics of oolite. Complex microhabitat spaces can be created in a variety of ways depending on the level of technological sophistication. A common method is to add blocks of salt to concrete reef forms as they are solidifying. After the concrete form has hardened, the salt portions can be dissolved away with an acid, leaving the concrete intact with void spaces where the salt formerly was. 3-D printing technology offers a methodology for creating more predicable microhabitat void spaces. 3-D printing technology allows for on-shore manufacturing, with the prospect of it-situ seafloor printing currently being researched.

Electrolytic metal formwork offers a less technological but proven method for producing coral-growing media. Metal formwork is dropped into the ocean and connected to a weak electrical current. The current creates a weak negative charge on the formwork, which attracts suspended materials out of the surrounding water and onto the formwork. The electrical current also creates localized alkalinic conditions around the structure, which favors coral growth. This has the added benefit for insulating corals from ocean acidification, a symptom of climate change that is also threatening the existence of coral species. An immediate advantage of electrolytic metal over concrete is the comparative ease of installation. A bare armature weighs a fraction of it's concrete equivalent when installed, but will grow to a comparable mass over time. This system is potentially better adapted to form itself into a continually linked system, as metal armatures linked together would be stitched together twice over, first by the minerals accreting on them, and then by the corals growing over top the rock layer. Disadvantages include a potentially less predictable distribution of microhabitat spaces, a manufacturing process dependent more on hands-on labor, and continual reliance on an electrical supply in order to continue to grow the reef medium and provide acidification protection.

Presently, several examples of electrolytic-produced coral reefs exist. In 1987, artist Michelle Oka Doner demonstrated the feasibility of the technology with her work Santa Monica Obelisks (Oakes 1995). Doner suspended a pair of 13.5 foot long metal-coated obelisks into the Atlantic Ocean off the coast of Key Largo, Florida while running an weak electrical current through their structure. After three years, she removed the results for display 2,800 miles away in Sana Monica, California. The columns accreted mineral deposits several inches thick in that time, along with a substantial accumulation of sessile marine life, including coral. In a 1991 speculative project entitled The Venice Accretion Project, Doner proposed using the technology to reinforce the crumbling submerged foundations of Venice's buildings.

Contemporary work on electrolytic reefs is currently being conducted by artist and activist Coleen Flannigan. Flannigan's aesthetically designed metal armatures accrete minerals and coral life while also attracting tourist visitors (Flannigan 2015). Flannigan's reef has successfully been installed in in Mexico. Similar projects are being developed elsewhere, such as in Indonesia (Eng 2012)

Figure 13. Santa Monica Obelisks. Michele Oka Doner. , 1990. (Photo: Oakes 1995)

Figure 14. Liku-Liku, Colleen Flanigan. 2011. Electrolytic metal armature. (Photo: Wolf Hilbertz)

Generation of Form

Design

The design for the new Osborne Reef presupposes a climate where our definition of ecological restoration has effectively transitioned away from a concern with the recovery of a former ecological condition. Indeed, this paradigm in already exists within the maintstream position of the restoration community. In 2005, The Society of Ecological Restoration (the world's professional organization for restoration ecologists) defined the process of ecological restoration as one of "assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. It is an intentional activity that initiates or accelerates ecosystem recovery with respect to its health (functional processes), integrity (species composition and community structure), and sustainability (resistance to disturbance and resilience) (Clewell 2005)". In line with these guidelines, this project operates within a paradigm that sets ecological benchmarks and hopes to generate a novel system that can achieve this level of ecological performance. The design proposal responds to three primary criteria: the mitigation of the existing, failed Osborne Reef, the production of new habitat for reef species, and the generation and assimilation of new ecologies. In order to accomplish this, the design consists of three general zones, the netted structure that covers the existing reef, a "tire memorial," or elevated and windowed structure that creates an array of views into the original Osborne Reef, and the "Sandy Bottom Botanical Garden," which serves as a farm to cultivate the keystone species of coral reefs and supporting sandy bottom ecosystems. More broadly, design strategies respond to the specific conditions on the site of the existing Osborne Reef, and propose a series of new programs that integrate a wide range of goals, including the mitigation of damage to nearby reefs, the production of new ecological habitat, introduction of recreational activities for divers, scientific monitoring of new and existing ecological habitat, and the production of diverse keystone species for nearby supporting ecosystems.

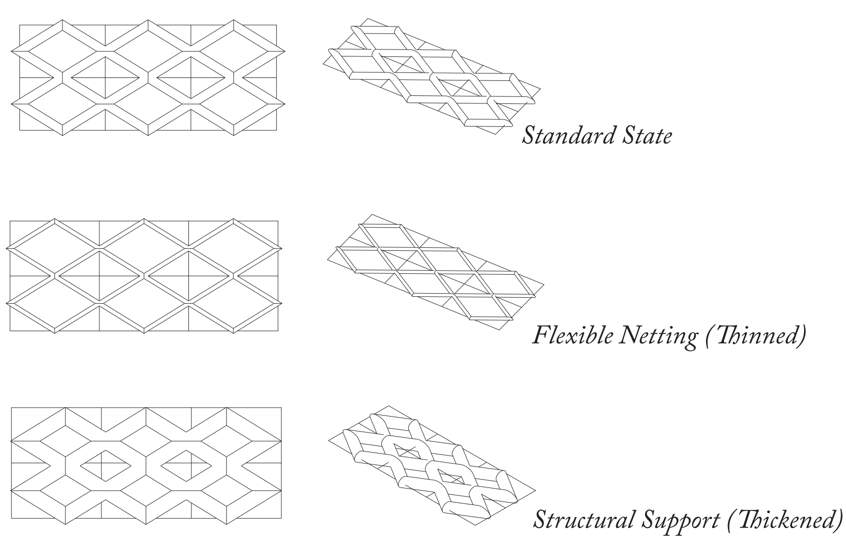
Due to the expansive nature of the site, design strategies favor an approach rooted in incrementalism. The project achieves this through the production of an artificial reef composed of modular units. These units are designed parametrically, as derivations of the same basic unit. This unit is based off a standard diagrid structure, which is then modulated parametrically to create an variety of arrangements, which respond to highly localized conditions that exist within the site. Advances in 3-D printing technology afford the opportunity to manufacture and organize these modular units in a way that creates a coherent pattern, which provides a novel approach to covering the tires left over from existing Osborne

Reef. This level of responsiveness creates the potential to generate microclimates for coral growth, at both the modular unit level (by creating units with varied micro-topography to stimulate coral growth and provide hiding spaces of other species), and the site level (by creating a mesh of varied heights that can accommodate the high level of species variety endemic to coral reefs while protecting corals from sand scour). Ultimately, by acknowledging its existence within an ecosystem where the lines between organic and synthetic are already physically blurred, the reef recreation project at Osborne Reef is able to realize new ecological possibilities for the site.

Variable Modularity

The reef recreation of the Osborne Reef creates what is effectively a netting structure that covers the existing tire reef, and also acts as a substrate for corals to grow. This structure also accommodates other human and ecological uses, at times creating apertures that allow divers to see through the artificial reef. These apertures are controlled through modulation of the same existing diagrid form. This form takes on an infinite number of variations through the deformation of its planar surface, and the contortion and manipulation of each individual unit. The end product of this modular system is a dynamic reef ecosystem.

Figure 15. Osborne Reef Net Structure Typologies



Netting Structure

The netting portion of the site is a diagrid structure that covers the existing tires, in order to keep them in place. The structure also grows corals, and creates a rippling topography that generates a variety of habitat types. In this netting portion of the reef, the manipulation of the cell occurs through a thinning and thickening of the structure itself. Areas covering tires with "significant" coral growth over 10 cm in dimeter (Quinn 2014) consist of thinner portions of the structure, which allow sunlight to penetrate the reef structure for coral growth, while securing the tires in place. The thicker areas act as structural portions of the canopy, and footings can be rooted in the ground, and ultimately connected to these thicker areas of the canopy. This provides a higher level of structural security for the reef itself, and protects it against tides and large offshore storms.

Tire Memorial

In the "tire memorial" portion of the site, the diagram shape becomes arrayed, and folded to create a module with vertical complexity. The overall structure creates a bubble shape, resulting in an underwater microclimate, with limited tide action. This allows for a wide range of species diversity to occur on the site. The modifications on the unit level accomplish two major goals. Firstly, a vertical complexity on the module level creates a variety of surfaces for many different types of coral to grow. This also serves as habitat for marine life that needs to take shelter in reefs. Second, the folding of the module opens up larger apertures, which serve as windows into the former Osborne Reef, and a remembrance of the original Osborne Reef ecological disaster. Overall, by manipulating the basic diamond shape nested within the diagrid, the Osborne Reef recreation is able to simultaneously address the tasks required to mitigate the ecological danger of the site, while also providing new recreational opportunities, and creating new ecological systems that accommodate a variety of coral species.

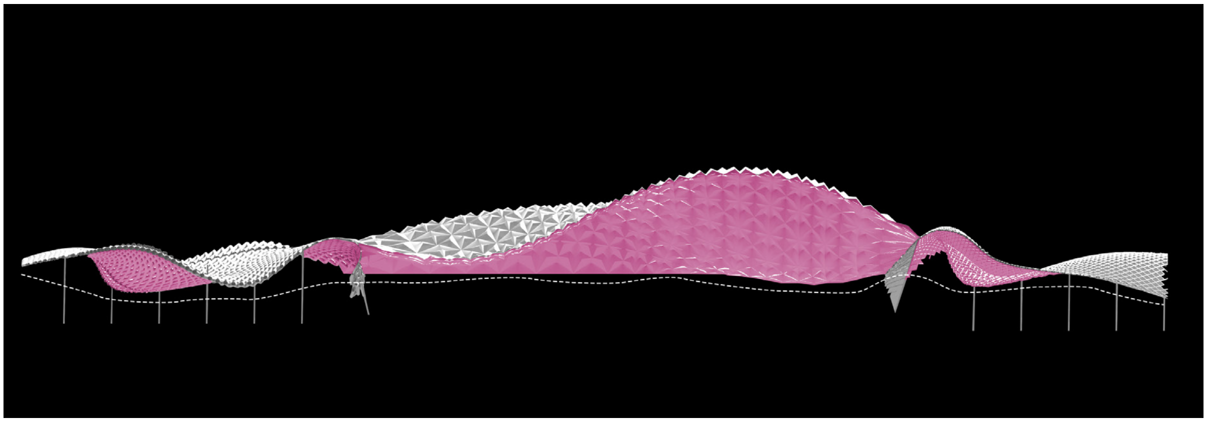


Figure 16. Diagrammatic Section indicating ocean floor and netting structure. Ocean floor indicated with dotted line.

Figure 17. Osborne Reef Tire Memorial Structure Typologies

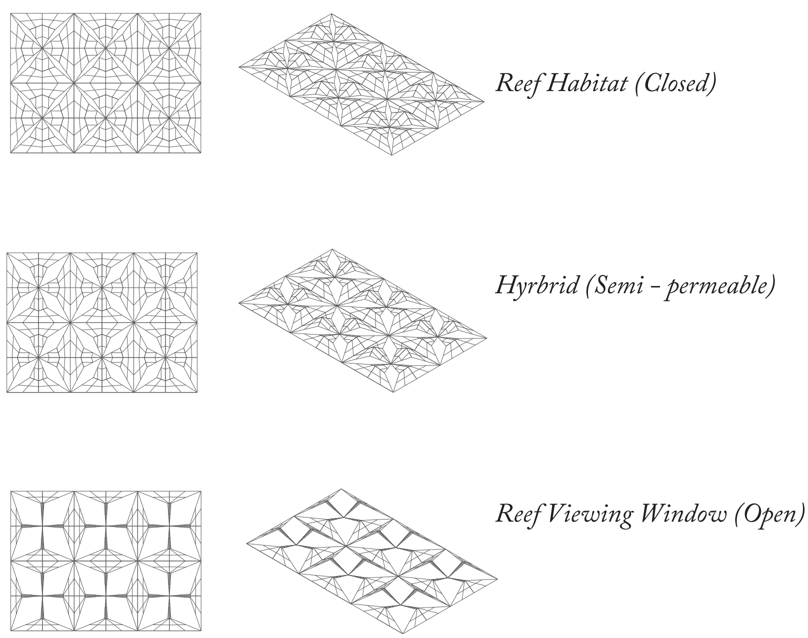


Figure 18. Exsiting Osborne Tire Reef Conditions with limited ecological interactions.

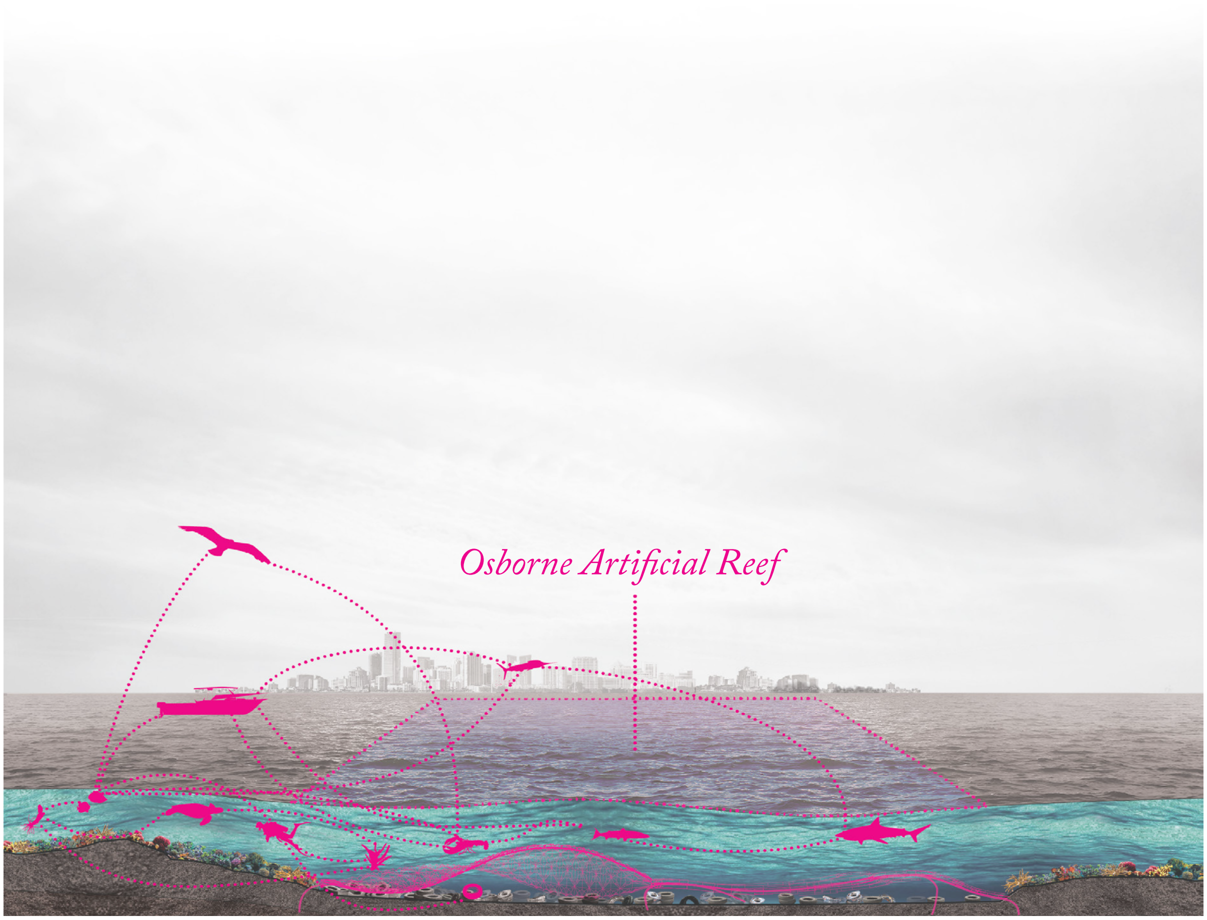


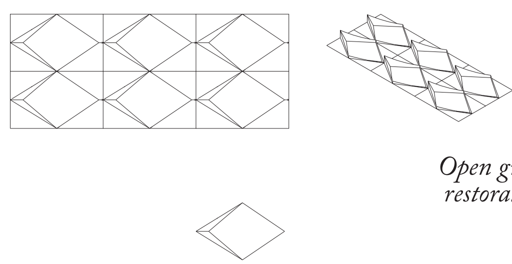
Figure 19. Proposed Netting Structure with enhanced ecological networks.

Sandy Bottom Botanical Garden

The botanical garden portion of the site addresses habitat diversity on a larger scale by "farming" a variety of species that are necessary for the security of coral reefs. This includes the keystone species that support both coral and sandy bottom ecosystems, such as sea grass, urchins, sea sponges, and experimental hybridized coral species. The structure itself applies a more specific module, with more limited surface manipulation. The module itself is scaled to be much larger than the netting and tire memorial portions. Instead of securing tires from the Osborne Reef, this new structure is rooted into the nearby sandy bottom ecosystem, and acts as a barrier between the species growing on the inside and the more barren sandy ecosystem taking place outside the structure. The diamond shape becomes more vertical, with slanted sides. The verticality exists to serve as a barrier to sand scour, which can harm many of the species growing within. It also shelters the species from excessive predation. The shape's vertical components also have sloped, diagonal walls. This slope exists to allow different species to enter and exit the individual cells, rather than creating a condition of complete isolation for the species within the botanical zone. Overall, this allows the large scale production of species necessary to grow reefs, not just on the Osborne site, but it can also contribute to other reefs within the region.

These three typologies rely on the modularity of a single component. Through the simple operations of scaling, rotating, folding, and thickening, the Osborne Reef can be recreated as a novel, ecologically complex habitat, sensitive to the area's underlying ecological needs.

Figure 20. Sandy Bottom Botanical Garden Typology



Open grid accomodates multiple restoration programs.

Figure 21. Possible Sandy Bottom Botanical Garden Species Restoration Programs

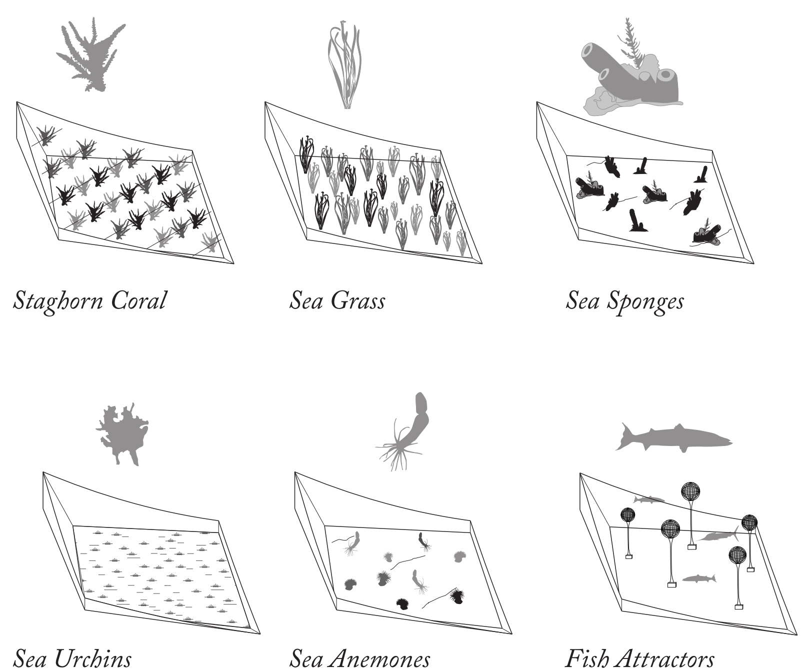


Figure 22. Existing Sandy Bottom

Figure 23. Proposed Sandy Bottom Habitat Botanical Garden

Deployment

Following the establishment of sufficient onshore fabrication facilities to keep up with demand, construction would first begin on the netting structure for the core infestation area. Work would begin at the areas of highest tire density and continue outward until the 36 acre site is netted. It is estimated that this netting would contain 676,000 tires, or approximately 36% of the total remaining tire infestation.

As deployment of the netting structure continues the next phase, constructon of the tire memorial, would begin. The tire memorial is a structural outgrowth of the netting structure designed to encapsulate the remaining 25,000 tires still bound by nylon and steel clips into their original tire reef form. Openings on the tire memorial will be positioned slightly larger than on the rest of the netting structure, allowing drivers a glimpse and access into the original reef as it was intended. The tire memorial will soften and disperse wave action against the remaining tire reef, thus preserving its historical value. In the event that the tire structures cannot hold together, the tire memorial would still serve to encapsulate and contain any loose tires that would result.

At this point, deployment of an optional anchored visitor center would occur, should sufficient interested and funding exist to warrant it. If not, plan would be held off until deemed appropriate. The visitor center would give tourists a place to interpret the reef and associated ongoing research that is as close to the site as possible without having to dive it. For divers, the site would be a jumping off point for underwater exploration of selected portions of the site. Fabricated components en route to the seafloor could pass through the visitor center when practical to futher highlight and demonstrate the deployment of new restoration technologies.

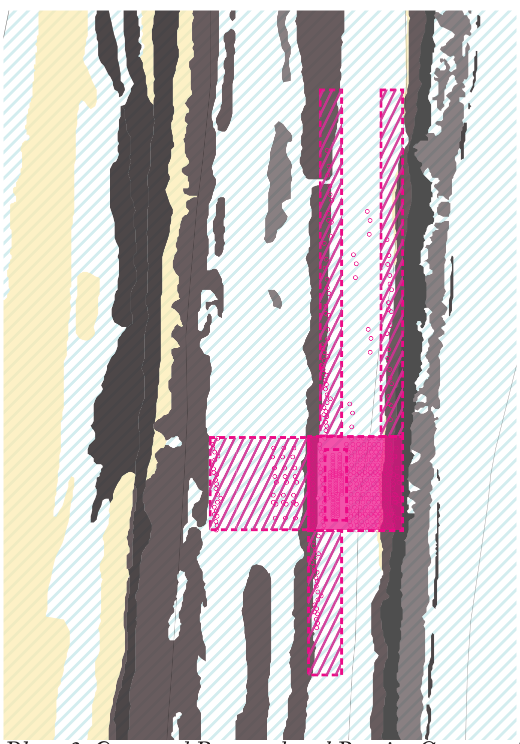
As the new reef takes shape so would the opportunities to interpret the seafloor. Existing shipwrecks and artificial reefs would become surrounded by the expanding netting intervention, and thus become literally woven into it's fabric.

Moving outward from the core infestation areas, tire removal activities paired with reef barrier building would continue north, south, and west of the core infestation site. As the barriers are built up, they could eventually be reinforced with veritical structures to further expand their coral growth potential as the threat of tires is lessened. Barrier structures would not initially be designed to grow coral, as their initial purpose would be to collect loose tires

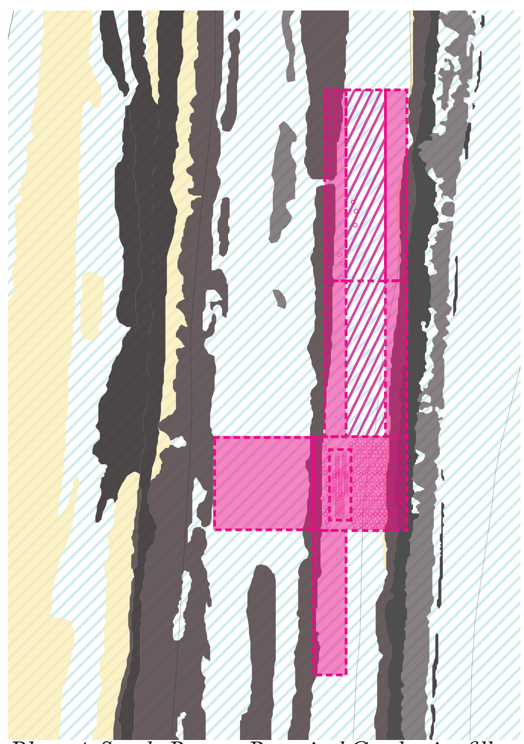
Figure 24: Phasing Strategy.

Phase 1: Blanketing Canopy over orginal 36 acre Osborne Reef Core Infestation Area

Phase 2: Construct Tire Memorial, option to begin anchored Visitor Center



Phase 3: Outward Removal and Barrier Construction



Phase 4: Sandy Bottom Botanical Garden in-fill

washing in from the sandy bottom. This could be as simple as not providing them electrical energy if they composed of electrolytic formwork, or sheathing them with a growth retardant if they are composed of reef friendly concrete.

Finally, paired with the creation of coral habitat would be an active pursuit of novel restoration methodologies for the regions' other imperiled life forms and habitat types. Less research has gone into subjects such as sea grass and sea urchin cultivation, and the sandy bottom in general. We propose that these subjects and more be studied in a sort of underwater botanical garden, located in the open sandy bottom areas surrounded by our intervention. Portions of these areas would be designated as conservation space for sandy bottom habitat, while other portions would be utilized for novel habitat cultivation methodologies.

Provided it could be done in an ecologically neutral manner, we hope that portions of the Osborne site could be used for energy production. This would be done both to attract lucrative funding partners in the form of energy companies and to develop, test, and implement new forms of underwater energy generation technology that would not harm ocean habitat. Energy produced on site could make the reef energy independent, providing power to possible electrolytic operations in addition to the visitor center. Depending on the level of potential adverse effects to sea life, some energy infrastructure, such as turbines, could be placed to the east of the Osborne site, past the third reef tract, where they would not be a threat to reef life. Other more complimentary energy technology, such as wave action collectors, could be located throughout the barriers and perhaps the blanket canopy and among the botanical garden if deemed safe enough.

Taken together, the intervention has the potential to take a failed experiment in novel restoration and transform it into a diverse patchwork landscape of conservation, research, production, and tourism.

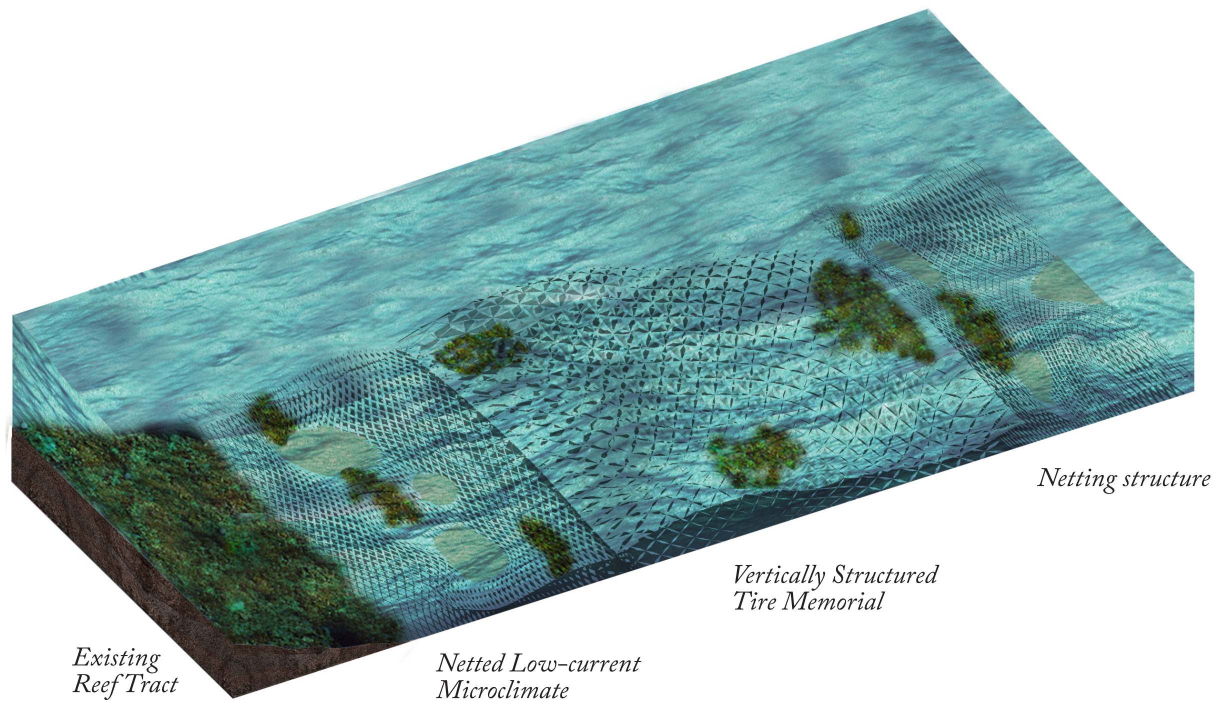


Figure 25 Osborne Reef - Initial Growth Phase

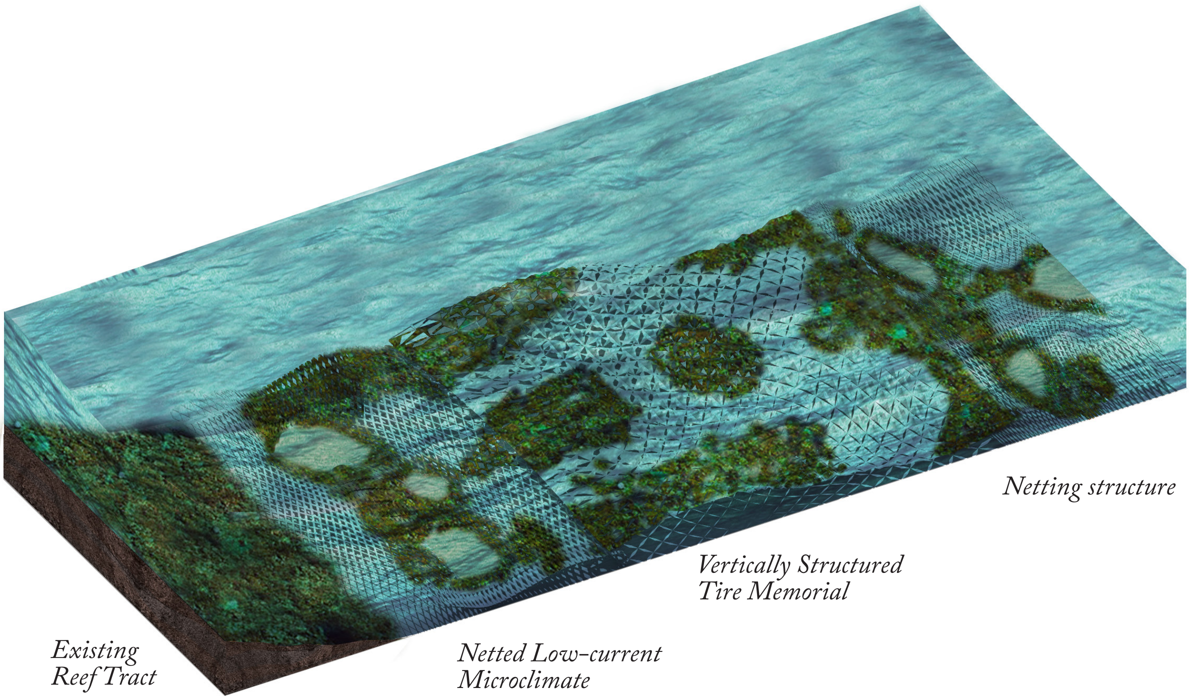


Figure 26. Osborne Reef - Intermediate Growth Phase

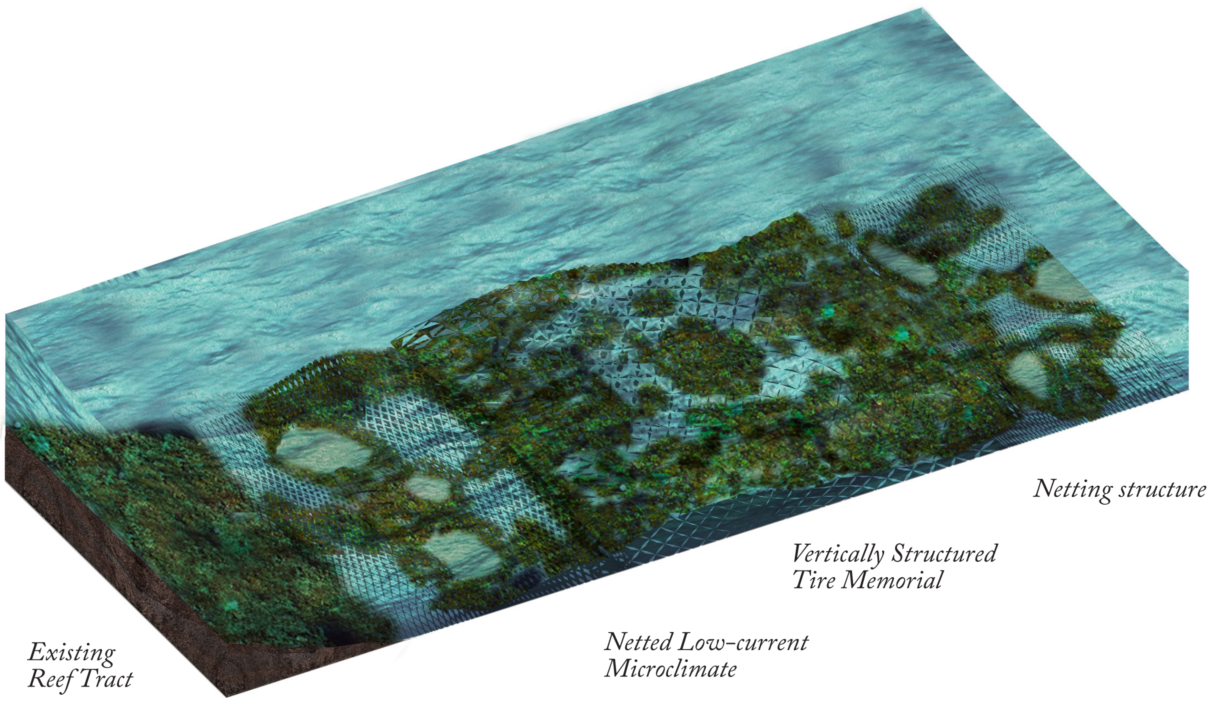


Figure 27. Diagrammatic Axon of full Reef Intervention - Climax Growth Phase

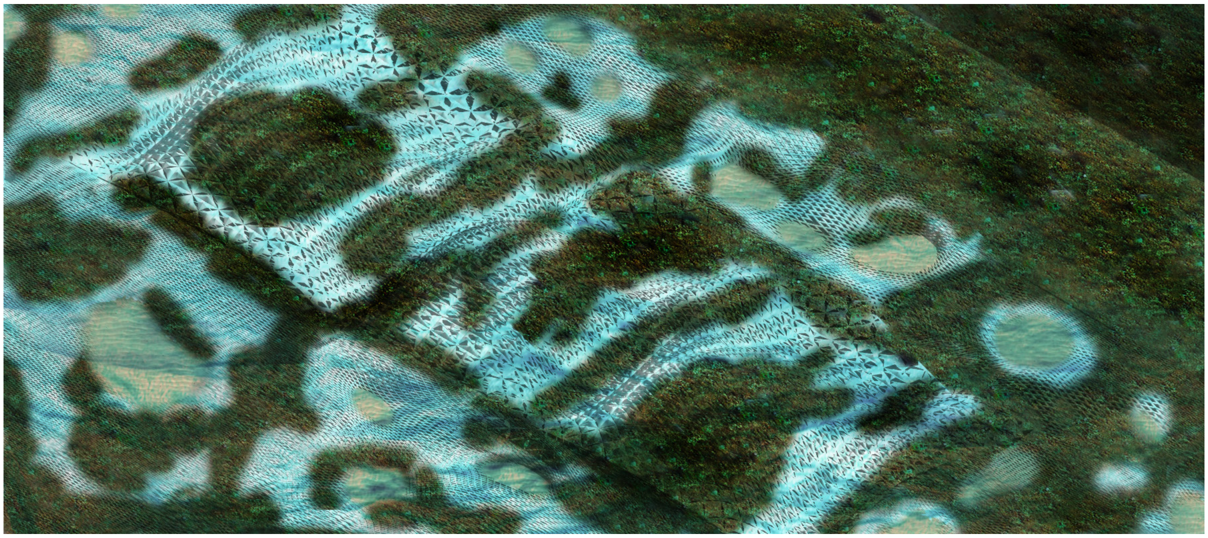


Figure 28: The New Osborne Reef, integrated into the surrounding seafloor.

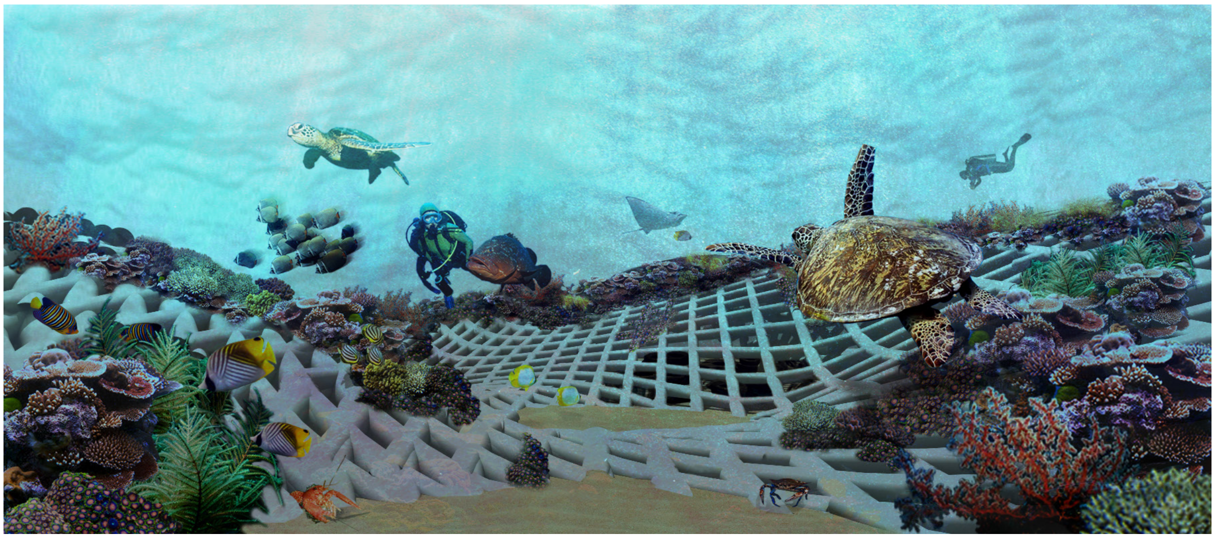


Figure 29: Contained tires and restored reef habitat at the seafloor.

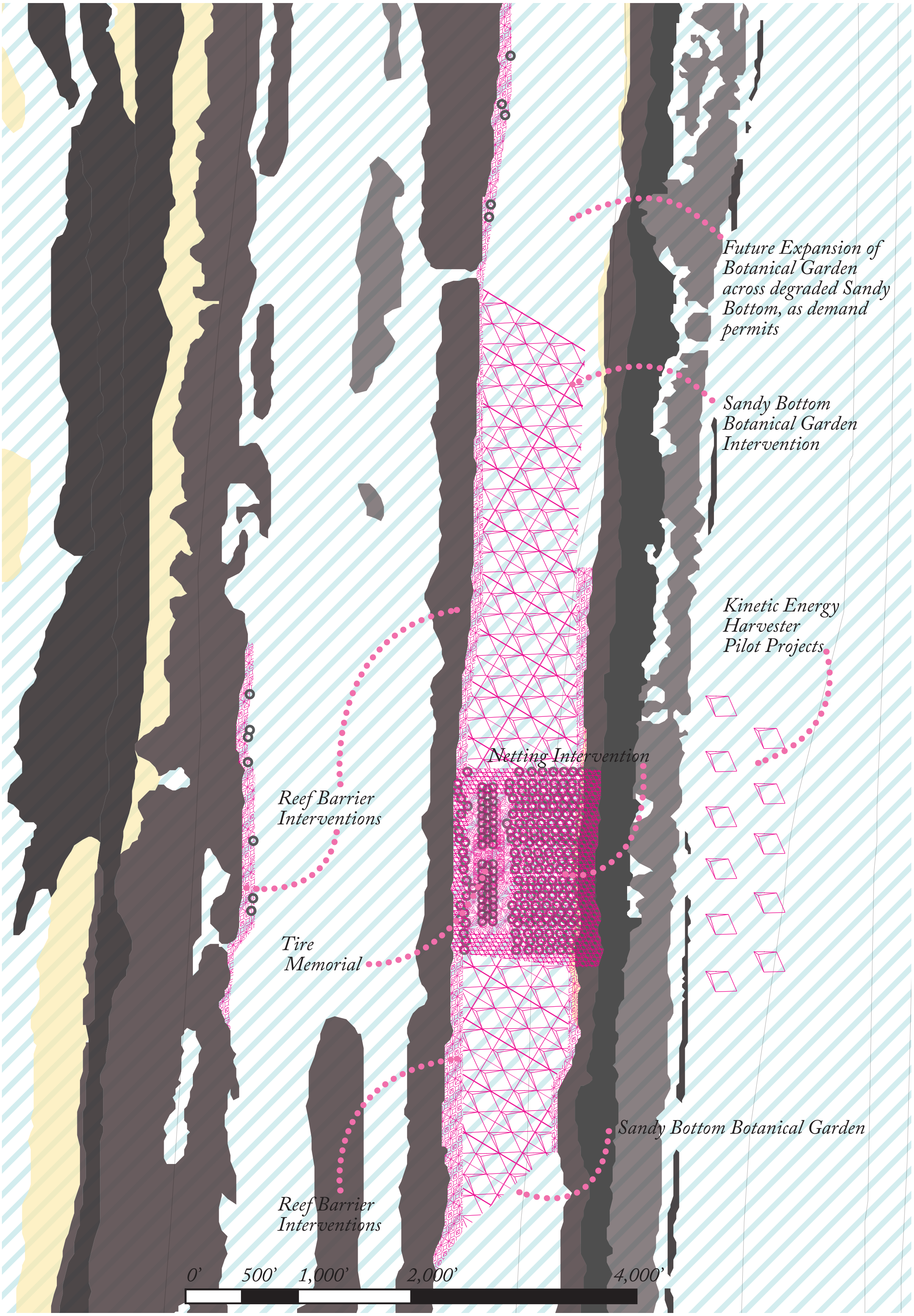
Management

Funding and managing the new Osborne Reef would be a challenging endeavor, owing to the cost of constructing experimental structures in an difficult underwater environment. Because it is not generally not visible to the public beyond specialist divers, generating initial widespread public interest could be difficult. Despite good intentions, Broward County has not been able to commit funding at the levels necessariy to completely remove the tires. For these reasons we would propose a large initial role for the United States Federal government. Promulgated specfically by presidential executive order in 1998, numerous Federal agencies, including the Deptartments of Interior, Commerce via the National Oceanic and Atmospheric Administration, Defence, State, Transporation, as well as the Agency or International Development and NASA have been tasked to various degrees with the observation, research, protection and restoration of coral reef ecosystems, both within and beyond U.S. territorial jurisdiction (Exec. Order 1998, Amson 1985).

Theoretically, the Federal Government is the only entity that would seemingly be willing to take on the enormous cost necessary to start such a project with no profit motive. The National Oceanic and Atmospheric Administration, or NOAA, has been empowered to fund coral reef restoration, marine debris removal, and public-private conservation partnerships through a series of granting programs (NOAA 2015). Both NOAA and the Department of Interior through various agencies are responsible for managing Federally-claimed territory. Over the last twenty years, The Department of Interior, specifically the Fish and Wildlife Service has shown an appetite for approaching new modes of conservation management. Through Urban Refuges Initiative, for example, the Fish and Wildlife Service has put directed resources into developing wildlife refuges adjacent to urban areas. This has been done to capitalize on opportunities to restore ecologically degraded waste spaces such as former industrial areas into novel spaces for nature, as well as to engage an American populace that is increasingly more urbanized. We propose a multi-partnered, multi-use refuge space to capitalize on the opportunity presented by the tire disaster.

Establishing actions for the Osborne Reef Refuge would be executed by Congress, establishing Osborne Reef as a National Wildlife Refuge. Alternatively, failing congressional action, an executive order could declare the region a Marine Sanctuary under the authority of NOAA, with NOAA bringing the USFWS on and a managing partner. Oceanic reserves such as Marine Sanctuaries have typically been administered by NOAA, mostly for passive use. However, this site would effectively be managed and partially developed by multiple

Figure 30. Osborne Reef National Marine Refuge - Diagrammatic Site Plan



public and private partners. We determine that the USFWS would be the more appropriate managing authority, given their tract record both with restoration activities and public-private partnerships throughout their Refuge system.

Following the establishment of the site as a National Wildlife Refuge - in this case a National Marine Refuge, work could begin to form a consortium of interested public and private entities to partner on the reef. Similar to how many contemporary Refuges are run, they would advise Refuge policy through an established Friends Group. In return, the Refuge could and would turn the management of selected parcels and activities over to the partners. Partners would be responsible for the cost of their committed activities but also given a degree of freedom in determining how their projects would fulfill agreed-upon benchmarks for conservation and restoration. Construction of the netting structure and barriers would be bid out to construction and fabrication firms, with management responsibilities vested with the Department of Interior and/or interested Universities. Monitoring and cleanup of the Barrier structures would be undertaken by local activist diver's groups that have long advocated for Osborne Reef, such as the Florida-based Bluewater Initiative and Project Baseline. Energy or infrastructure firms would be approached to partner on selected energy production projects and would be represented as project partners as well. Management of the habitats created by the netting structure and eventually plots within the botanical garden would be apportioned to interested research partners. This would potentially include but is not limited to existing Florida-based restoration non-profits such as Nova Southeastern University, Coral Morphologic, and the Coral Restoration Foundation, among with other potential partners that could prove that they have a good idea. Funding for these research projects would come from the grants offered from the Federal government, matched with funding from the Friends Group and it's partners directly, as well as well as local and state matching funds if available. Given the development realities in the Miami area, it is possible that mitigation activities for nearby development, such as destructive channel dredging, could be directed towards Osborne Refuge needs, in the form of actions or funding.

Conclusion

Osborne Reef was concieved as a means to opportunistically and cheaply dispose of garbage with the added value of creating habitat. The project failed, creating a local and regional ecological threat amid the wider global threat of climate change. We have proposed a containment system that is proactive, in the sense that it encourages reef growth in concert with tire removal. It is modular. This allows it to grow with the availability of funding and new technologies, allowing it to improve over time as it helps determine best practices in a changing ocean environment. We have proposed emerging technologies such as 3-D printing and parametric modelling to work as drivers of the project, but have left spaces in the project open, such as in the Sandy Bottom Botanical Garden, for future innovations that we cannot predict. Finally, we have proposed a multi-part management strategy that gains strength from combining the resources and motives of disparate private and institutional parties with the rigorously high conservation standards of the Federal government.

We believe that the development of the new Osborne Reef National Marine Refuge would over time serve as a model for marine restoration practices for the world. The scalable nature of our modular interventions can respond to a wide variety of topographies and available funding, whether or not tires are even a threat.

Much like the tires that Osborne currently scatters, the new Osborne Reef would spread new methods of conservation. Osborne stands currently as an example to the world of how not to protect corals. We seek to redeem that legacy through a mission that first addresses the fruits of it’s failure while providing and exporting ever-better methodologies for coral restoration as our changing world demands.

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